SUBSOILING, DEEP TILLING, AND SOIL DYNAMITING IN THE GREAT PLAINS[1]

By E. C. Chilcott, *Agriculturist in Charge*, and John S. Cole, *Agriculturist, Dry-Land Agriculture Investigations, Bureau of Plant Industry, United States Department of Agriculture*

GENERAL DISCUSSION OF SUBSOILING, DEEP TILLING, AND SOIL DYNAMITING

There is perhaps no agricultural operation that is so often and enthusiastically advocated and at the same time so little practiced as that of loosening or tilling the soil below the depth reached by the ordinary plow.

The supposed necessity or desirability of such an operation appears to be based on a widespread belief that only that part of the soil loosened and moved by man with his implements of tillage is utilized by nature in the production of crops; that this part of the soil is the only part that participates in the storage of water to be recovered by the crop; that the development and growth of the roots of crop plants is limited to this portion of the soil, and that this is the only portion of the soil from which plant food may be obtained by the crop.

A less extreme belief recognizes that these things are not entirely limited to the portion of the soil that man loosens, stirs, pulverizes, or inverts, but holds that the soil so treated provides a more effective medium for their action than does the undisturbed soil.

Such beliefs apparently either overlook the luxuriant vegetation produced on land that has never known the tillage implements of man or assume that the roots of crop plants are essentially different in their relation to the soil than those of other plants or of the same plants growing wild.

Studies of the root systems of agricultural crops have shown that in the deep soils and subsoils of the prairies and plains the roots of annual crops are well distributed through the soil to a depth of 3 feet or more.

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[1] The experimental work of this investigation was carried out at 12 field stations of the Office of Dry-Land Agriculture Investigations. The following members of the scientific staff of the office assisted in the experiments at their stations: J. M. Stephens, superintendent, Judith Basin Substation, Moccasin, Mont., in charge of northern district; O. J. Grace, superintendent, Akron (Colo.) Field Station, in charge of central district; E. F. Chilcott, superintendent, Woodward (Okla.) Field Station, in charge of southern district; W. P. Baird, assistant, Judith Basin Substation; A. E. Seamans, assistant, Huntley (Mont.) Field Station; W. A. Peterson, superintendent, F. E. Cobb and N. O. Henchel, assistant arboriculturists, Max Pfaender, assistant in horticulture, J. T. Sarvis, physiologist, and R. S. Towle, assistant, Mandan (N. Dak.) Field Station; O. R. Mathews, assistant. Bellefourche (S. Dak.) Field Station; F. L. Kelso, superintendent, Ardmore (S. Dak.) Field Station; Albert Osenbrug, assistant, Scottsbluff (Nebr.) Field Station; W. E. Lyness, assistant, Archer (Wyo.) Field Station; J. F. Brandon, assistant, Akron (Colo.) Field Station; A. L. Hallsted, assistant, Hays (Kans.) Substation; C. B. Brown, assistant, Garden City (Kans.) Substation; L. N. Jensen, assistant, Amarillo (Tex.) Field Station; H. G. Smith, superintendent, Tucumcari (N. Mex.) Field Station.

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If the water stored within the zone of normal root development is not sufficient to meet the needs of the crop, the roots will continue during the life of the plants to penetrate deeper, provided the soil below is wet. Under such conditions the roots may successively occupy the fourth, fifth, and sixth foot. The roots of winter wheat have been traced to a depth of 8 feet. In this connection it should be noted that fertility of the subsoil is a general characteristic of the soils of semiarid regions. Roots do not penetrate dry soil, even though there may be wet soil beneath it. Where shallowness of soil restricts root development to a depth less than normal, the plants may attain complete development, provided the water content of the zone occupied by the roots is maintained above the limit of availability. The shallower the soil or the smaller the quantity of available water it can retain the more dependent is the crop on rains that fall while it is growing.

All field studies of root systems have been made on land given ordinary plowing, generally to a depth of about 6 inches. No comparative studies of root systems as developed in deep and in shallow plowing have been made. But studies that have been made on the quantity of water stored in the soil, the depth to which it is stored, the depth from which it is used and the degree to which it is exhausted, and the behavior and yield of the crop on land tilled to different depths all afford an abundance of indirect evidence that the form and extent of root systems are not primarily affected by the depth of tillage.

Extensive soil-moisture studies that have been made in connection with the investigations reported in this paper indicate that the ability of the soil to take in or to retain water, or to give up water to the crop, is not determined by the depth of tillage. Sands and light sandy soils offer little resistance to the entry and downward passage of water. They are little changed and certainly not improved in this respect by cultivation. With the heavier clay soils in which penetration is slower and more difficult it would seem that there was more opportunity for improvement by a mechanical loosening. The result is not, however, what it might at first thought appear to be. The mechanical loosening that may be affected when such soils are dry enough to be loosened by tilling is of no consequence so long as the soil remains dry. When rains come and water enters the soil, it carries soil material with it in its downward passage through the loosened soil. The clay expands on becoming wet and the loosened and wetted area becomes an amorphous mass. On drying, the soil contracts. A part of the shrinkage is downward, and a part of it is lateral. The lateral shrinkage results in cracks that may open the soil as effectively as any tillage operation. Mathews (*3*)[1] has shown that when allowed opportunity for free expansion a soil when wet may occupy 2½ times the volume it did when dry.

[1] Reference is made by number (italic) to "Literature cited," p. 521.

One cycle of wetting and drying overcomes the effect of cultivation. As Mosier and Gustafson (*4*) say—

> The subsoil ran together as soon as it was wet and became approximately as it was before.

It is frequently stated that deep tillage prevents run-off by facilitating penetration. Soil-moisture studies show that in the Great Plains penetration and run-off are determined more by the condition of the immediate surface than by the depth to which the soil has been cultivated. Run-off in the Great Plains other than that from the rapid melting of snow on frozen ground is from torrential rains in which the precipitation of a few minutes or hours is measured in inches. Beating rains of this character smooth and compact the surface so that the run-off is heavy. As the great volume of water that constitutes the run-off does not get beneath the surface, the condition of the subsoil is of no importance in determining its amount. The finer and smoother the surface has been made by cultivation the more easily and quickly is it reduced to a condition that resists penetration and facilitates run-off. The Akron, Colorado, soil, on which the results of subsoiling have been especially unfavorable to the practice, is a good example of a soil from which there often may be heavy run-off from a smooth and compacted surface overlying a very loose and open subsoil.

Many cases have been noted in the course of these experiments where the amount of water that entered the soil from a heavy rain was greater on a dry, cracked stubble than on a plowed field.

Under the semiarid conditions of the Great Plains, where production is determined by the quantity of water available to the crop, the amount of water that enters and is retained by the soil is not determined by the depth of cultivation, and consequently is not increased by an increase in such depth. Under more humid conditions, where rainfall is sufficient to fill the soil regardless of the amount that may be lost by run-off, the depth of cultivation can not add to the amount retained and so can not be a determining factor, in so far as this item is concerned.

It must be recognized, however, that the possible combinations of conditions of looseness, fineness, and water content of subsoil and surface and the character and amount of rainfall are so many that they are seldom exactly duplicated, particularly in semiarid regions. Different combinations of these factors may give rise to different results, as is clearly shown both in soil-moisture studies and in the crop yields reported in this paper. The study of root systems and of soil moisture indicates that the effect or lack of effect of differences in the depth of tillage is accurately measured by crop yields. From the average yields obtained it may be safely assumed that under the soil and climatic conditions obtaining in the region where the experiments were conducted a combination of factors favorable to deep tillage does not occur often enough nor result in increases great enough to warrant its general practice.

It is mistaking or failing to recognize the purpose of plowing that leads to the belief that its efficiency increases with its depth even though that depth be extended below all practical limits of cost and effort. Plowing does not increase the water-holding capacity of the soil, nor the area in which roots may develop or from which the plants may obtain food. Plowing removes from the surface either green or dry material that may encumber it, provides a surface in which planting implements may cover the seed, and removes or delays the competition of weeds or plants other than those intended to grow, and in some cases by loosening and roughening the immediate surface checks the run-off of rain water. All these objects are accomplished as well by plowing to ordinary depths as by subsoiling, dynamiting, or deep tilling by any other method. There is little basis, therefore, for the expectation of increased yields from these practices, and the results of the experiments show that they have been generally ineffective.

EXPERIMENTS WITH SUBSOILING IN THE GREAT PLAINS

There are here reported results of subsoiling at 12 stations of this office in the Great Plains area for a total of 66 station-years, or an average of 5½ years at each station. From four to seven crops have been grown each year at each station. The crops under trial have been spring wheat, winter wheat (*Triticum aestivum*), oats (*Avena sativa*), barley (*Hordeum* spp.), flax (*Linum usitatissimum*), corn (*Zea mays*), kafir, milo, broom corn, sorghum (*Audropogon sorghum*), and cotton (*Gossypium* spp.), as shown in the results from the individual stations.

The length of time covered and the wide range of climatic conditions encountered in these experiments make the results representative of the widest range of conditions likely to be experienced in the region.

Figure 1 is a map of the Great Plains, showing the location of the field stations at which experiments have been conducted.

METHOD OF WORK

The results with subsoiling are all from continuous cropping of land to the crop under study. In this series of continuously cropped plots there are in general five methods under trial: Spring plowing, fall plowing, alternate cropping and summer tilling, subsoiling, and listing. In this study the results from the subsoiled plots, which are designated in the fields and notes as the "E plots," are compared with those from the fall-plowed plots, known as the "B plots." Except for the subsoiling practiced on E, these plots are treated exactly the same. They are plowed as early in the fall as is practicable after the crop has been removed. The plots are plowed to a good depth, the standard being set at 8 inches.

In addition to the plowing of plot E, a subsoiler is run in the bottom of the furrow, loosening the soil to a further depth of 6 to 8 inches, or to a total depth of 14 to 16 inches. The variation from this depth is hardly more than 2 inches either way. In general, subsoiling is done for two years in succession, and then is omitted for two years. The present outline calls for subsoiling at all stations in the fall of 1915, 1918, and 1919. The ground may be worked down in the fall or left rough over the winter. In the early years of the work these plots were harrowed immediately after plowing and kept cultivated during the fall, but the tendency has been more and more to leave them rough over the winter. This is considered the better practice both for catching snow and preventing run-off and soil blowing, and at the same time it reduces the expense of crop production.

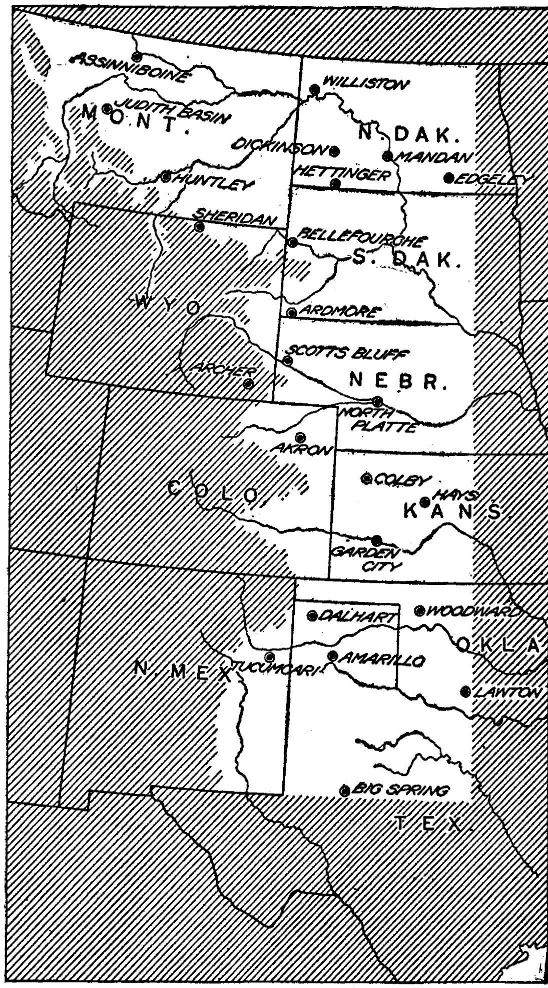

FIG. 1.—Map of the Great Plains area, which includes parts of 10 States and consists of about 400,000 square miles of territory. Its western boundary is indicated by a 5,000-foot contour. The location of each field station within the area is shown by a dot within a circle (⊙).

In some cases where it has been impossible to plow as early as desired, the stubble has been disked and the plowing done later.

In the spring the ground is finally prepared for seeding by the necessary use of the disk or smoothing harrow, or both.

Seeding is done with standard farm machinery at what is believed to be the best date and rate per acre.

The plots are 2 by 8 rods, or 0.1 acre in size. The B and E plots of any one crop are separated on their long dimension by the C and D plots, or an interval of 78 feet. The different crops may be more widely separated, but all are within a field of approximately 20 acres at each station.

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METHOD OF STUDY AND PRESENTATION OF RESULTS

Tables I to XII, inclusive, present in a separate table for each field station the yields of each crop each year on plot B (not subsoiled) and on plot E (subsoiled). The average yield of each plot for the entire period of years is also presented. The principal comparisons have been made and the conclusions of the effects of subsoiling drawn from the annual and average yields. But in order to obtain a uniform expression of difference on which to calculate the probable error of the results, and through which to compare the relative effect upon different crops and at the several stations, it has seemed necessary to express the differences in some form of ratio or percentage.

A thorough study of the data has been made by means of percentages calculated on four different bases. The ratios of the average yields have been computed for each crop at each station by dividing the average yield of plot E by the average yield of plot B. This single calculation does not afford either an expression of the results each year or opportunity for the determination of the probable error based on annual differences.

In each experimental field there are a large number of plots of each crop grown each year by various methods. The difference in yield between B and E each year has been calculated as a percentage of the average yield of all plots of the same crop in the field for that year. Objection has been made to the use of this method for this particular study, for the reason that with some crops the yields of these methods are below the general average and with other crops they are above it. This results in some cases in a disproportionate valuation of the entity under study. The average departure of the results as calculated by this method from those obtained by the first method is so high as to make its use for the present study unsatisfactory.

The difference in yield between plots B and E each year has been calculated as a percentage of the yield of B, which may be considered as the control plot, or the one giving the yield that it is sought to increase on E by means of subsoiling. For the results in hand this method gives undue weight to comparatively small differences in yield as the yield of the plot selected as the base of comparison approaches zero. There are so many of these cases that the results of comparison by this method are not satisfactory when compared with actual differences in average yield.

This objectionable weighting of small differences in yield is largely overcome and the results smoothed by using the arithmetic mean of the yield of the two plots under study as the base on which to calculate the difference between the two as a percentage. This method tends, however, to reduce the percentage when it is above and to increase it when it is below 100. In over half the comparisons the ratios depart from 100 by less than 10, and within this range the distortion is not great. The average results are further made up of varying combinations of increases and decreases, so this method is more satisfactory in the averages as determined by it than might at first be thought possible. It is this method that has been adopted for presentation. With each pair of comparable yields in Tables I to XII is given the percentage of the yield of plot E to the mean of the yield of B and E. These percentages are averaged at the right, and the probable error of this average is given. In Table XIII these average ratios and probable errors are assembled and further averaged by crops and by stations. The data in this table are presented graphically in figures 2 and 3.

In these tables and charts a percentage of 100 shows that there was no difference in the yield of the two plots, a percentage above 100 shows that the higher yield was from the subsoiled plot, and a percentage below 100 shows that the higher yield was produced on the plot not subsoiled.

It is recognized that the use of ratios weights the results, and that averages of such ratios are not the same as the ratios of the averages. They are not, therefore, accurate quantitative expressions of the results and are not a measure of the economic value of a method as compared with a control. They are not, however, in the present study misleading in direction, and serve a useful purpose of facilitating comparisons between things otherwise difficult of direct comparison.

JUDITH BASIN FIELD STATION

The field station at Moccasin, Mont., in the Judith Basin, is located on a heavy clay soil of limestone origin. The soil is apparently very rich in available fertility. It is underlain at a depth of approximately 3 feet with a limestone gravel that is closely cemented with lime materials. The gravel subsoil, which extends to a depth of about 30 feet, is practically free from soil. While it is so closely cemented that it does not unduly drain the soil, it is not of a character to allow the storage of available water or the development of roots within it.

Comparative results of fall plowing and of subsoiling are available for spring wheat, winter wheat, oats, barley, corn, and flax for the seven years 1910 to 1916, inclusive. Crops were raised on this land in 1908 and 1909, but the first subsoiling was not done until the fall of 1909. Hail in 1912 destroyed all crops except winter wheat and flax. The yields of these crops were considerably reduced by the storm, but as the damage was relatively the same on each plot, the yields are used. The winter wheat crop of 1916 was lost by winterkilling.

The E plot for each of the crops was subsoiled in the fall of 1909, 1910, 1911, 1913, and 1915.

The yields and the ratios as previously described are presented in Table I. None of the average differences observed are significant, the departures from the mean being very small and either less or only slightly greater than their probable errors. This is true of all crops except barley, which, from the results at this station alone, would appear to be peculiarly benefited by subsoiling. This is a point not supported by the evidence of the 10 other stations at which barley is grown and therefore must be attributed to a soil difference which has been observed and to damage by gophers to the B plot in at least two seasons. While this damage has been noted in the field, it has not been taken into account in the tables. The year of 1913 is the only year in the series when all crops yielded as much, or more, on the subsoiled plot as they did on the ordinary plowed one. While it is probable that the relation is only a coincidence, it is worthy of note that no subsoiling was done in the fall of 1912 in preparation for this crop. The average results of all crops, including barley, at this station is only 103, with a probable error of 1. The conclusion is that subsoiling has been without practical effect.

TABLE I.—*Yields at the Judith Basin Field Station, Moccasin, Mont., of spring wheat, winter wheat, oats, barley, corn, and flax each year from 1910 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of corn are expressed in pounds of stover per acre; of other crops in bushels of grain per acre]

Crop and plot.	Yield or ratio.								Probable error of mean ratio.
	1910	1911	1912	1913	1914	1915	1916	Average.	
Spring wheat:									
Plot B	14.0	22.0	(a)	18.5	15.8	27.0	21.1	19.7	......
Plot E	15.0	23.5	(a)	22.8	16.5	25.5	20.0	20.6	......
Ratio of E to mean	103	103	......	110	102	97	97	102	±1.3
Winter wheat:									
Plot B	24.0	23.5	12.2	23.2	16.3	28.5	0.0	18.2	......
Plot E	23.2	22.4	12.5	26.2	15.5	28.3	0.0	18.3	......
Ratio of E to mean	98	98	101	106	97	100	....	100	±0.9
Oats:									
Plot B	20.9	51.5	(a)	65.0	49.3	50.6	45.6	47.2	......
Plot E	25.3	53.0	(a)	65.0	40.6	57.1	43.1	47.4	......
Ratio of E to mean	110	101	......	100	90	106	97	101	±1.9
Barley:									
Plot B	12.5	24.1	(a)	21.9	18.1	24.0	20.5	20.2	......
Plot E	15.0	32.6	(a)	32.9	23.5	25.8	20.5	25.1	......
Ratio of E to mean	109	115	......	120	113	104	100	110	±2.2
Corn:									
Plot B	2,900	7,000	(a)	4,000	3,700	8,450	6,200	5,375	......
Plot E	3,650	4,780	(a)	5,800	5,000	8,000	6,200	5,572	......
Ratio of E to mean	111	81	......	118	115	97	100	104	±4.2
Flax:									
Plot B	6.2	13.2	5.4	12.9	9.1	16.0	10.3	10.4	......
Plot E	6.5	14.1	4.9	13.2	10.7	17.3	10.3	11.0	......
Ratio of E to mean	102	103	95	101	108	104	100	102	±0.9

[a] Crop destroyed by hail.

HUNTLEY FIELD STATION

The field station at Huntley, Mont., is located in the valley of the Yellowstone River at the foot of the first bench. The soil is a heavy gumbo clay to the depth of about 8 feet. Underlying the soil is a considerable depth of free-drained gravel.

Table II presents the yields and ratios of four years for spring wheat, oats, flax, and corn, and three years for winter wheat at this station. The only consistent results to be noted either by years or by crops are that the corn and winter-wheat crops each year have been the heavier on the subsoiled plot, while with flax the reverse has been true. The differences, however, are not enough greater than the probable error to make them significant, particularly when considered in connection with similar comparisons of the same crops at other stations.

TABLE II.—*Yields at the Huntley (Mont.) Field Station of spring wheat, winter wheat, oats, corn, and flax each year from 1913 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Croop and plot.	Yield or ratio.					
	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:						
Plot B	11.8	20.2	25.3	7.8	16.3	
Plot E	14.5	17.5	25.5	6.2	15.9	
Ratio of E to mean	110	93	100	89	98	±3.4
Winter wheat:						
Plot B	....	25.7	13.3	12.7	17.2	
Plot E	....	27.8	13.6	15.5	19.0	
Ratio of E to mean	....	104	101	110	105	±2.0
Oats:						
Plot B	34.0	48.4	56.9	17.8	39.3	
Plot E	39.3	52.8	61.9	16.9	42.7	
Ratio of E to mean	107	104	104	97	103	±1.5
Corn:						
Plot B	14.8	13.2	40.6	25.4	23.5	
Plot E	25.7	13.9	42.5	29.6	27.9	
Ratio of E to mean	127	103	102	108	110	±4.1
Flax:						
Plot B	12.5	8.4	16.7	5.4	10.8	
Plot E	11.9	4.7	13.4	4.5	8.6	
Ratio of E to mean	98	72	89	91	88	±3.7

MANDAN FIELD STATION

The record for the Mandan (N. Dak.) Field Station covers only two years, but spring wheat has been replicated four times each year and all other crops, except flax, three times each year. On the main field the soil is a light, sandy loam with a more sandy subsoil. On this field spring wheat appears twice and the other crops once. The soil of the south field is a heavy clay loam with a heavier subsoil. All crops except flax are grown in duplicate on the south field.

TABLE III.—*Yields at the Mandan (N. Dak.) Field Station of spring wheat, oats, barley, corn, and flax for 1915 and 1916 on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the two years; the ratio of the yield on E to the mean of the yield on B and E each year and replication, the mean ratio, and the probable error of the mean ratio*

[Yields in bushels per acre. Flax one, spring wheat four, and other crops three replications each year]

Crop and plot.	Yield or ratio.									
	Main field.		South field.				Main field.		Average.	Probable error of mean ratio.
			II		IV					
	1915	1916	1915	1916	1915	1916	1915	1916		
Spring wheat:										
Plot B	32.1	18.5	30.4	17.8	31.3	17.0	21.8	18.7	23.5	
Plot E	31.7	18.8	24.8	15.5	25.6	16.0	27.1	18.2	22.2	
Ratio of E to mean	99	101	90	93	90	97	111	99	98	±1.6
Oats:										
Plot B	59.8	57.5	81.3	63.4	74.7	52.2	.....	.....	64.9	
Plot E	57.5	57.2	68.4	59.1	69.1	60.3	.....	.....	61.9	
Ratio of E to mean	98	100	91	96	96	107	.....	.....	98	±1.3
Barley:										
Plot B	57.0	26.7	58.3	28.5	52.7	24.0	.....	.....	41.2	
Plot E	49.7	29.2	50.8	26.5	54.3	27.3	.....	.....	39.6	
Ratio of E to mean	93	104	93	96	101	109	.....	.....	99	±2.0
Corn:										
Plot B	26.7	49.1	28.6	28.9	29.2	35.0	.....	.....	32.9	
Plot E	24.8	44.5	20.0	33.8	26.3	34.1	.....	.....	30.6	
Ratio of E to mean	96	95	82	108	95	99	.....	.....	96	±2.0
Flax:										
Plot B	13.1	5.2	.....	.....	.....	.....	.....	.....	9.2	
Plot E	14.8	6.9	.....	.....	.....	.....	.....	.....	10.9	
Ratio of E to mean	106	114	.....	.....	.....	.....	.....	.....	110	±3.4

The results are presented in detail in Table III. Of the 28 comparisons afforded, only 9 appear to be in favor of subsoiling. These are not confined to particular crops, to either year, or to either type of soil.

Production from all methods was heavy in both years. The mean ratio of all crops is 100, with a probable error of 1.6. With all crops except flax the average result is slightly against subsoiling, but by a margin less than the calculated probable error. Flax from an unduplicated pair of plots shows an apparent increase from subsoiling, but as this result with this crop in comparison with others is exactly contrary to those obtained at Huntley it must be concluded that the departures in each case are due to the experimental error. If this conclusion is correct, subsoiling has been without significant effect at this station.

BELLEFOURCHE FIELD STATION

The Bellefourche Field Station, near Newell, S. Dak., is located on a heavy clay soil derived from the decomposition of Pierre shale. From the soil at the surface there is a rapid change to broken but undecomposed shale. Near the bottom of the second foot there is a comparatively impervious layer of soil.

TABLE IV.—*Yields at the Bellefourche (S. Dak.) Field Station of spring wheat, winter wheat, oats, corn, and barley each year from 1909 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Crop and plot.	Yield or ratio.									
	1909	1910	1911	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:										
Plot B	23.3	0.0	0.0	0.0	7.9	4.8	57.7	10.8	13.1	
Plot E	28.5	0.0	0.0	0.0	6.8	4.7	55.6	16.6	14.0	
Ratio of E to mean	110	......	......	......	93	99	98	121	104	± 3.8
Winter wheat:										
Plot B	34.4	0.0	0.0	0.0	21.8	13.4	20.4	8.8	12.4	
Plot E	29.3	0.0	0.0	0.0	18.7	14.7	25.2	8.5	12.1	
Ratio of E to mean	92	......	......	......	92	105	111	98	100	± 2.9
Oats:										
Plot B	46.9	0.0	0.0	6.6	15.8	24.7	119.7	23.1	29.6	
Plot E	60.8	0.0	0.0	7.3	16.3	20.3	118.1	21.1	30.5	
Ratio of E to mean	113	......	......	105	102	90	99	95	101	± 2.3
Barley:										
Plot B	25.0	4.8	0.0	0.0	8.9	7.1	71.5	33.6	18.9	
Plot E	33.8	0.0	0.0	0.0	7.8	6.3	78.9	29.2	19.5	
Ratio of E to mean	115	0.0	......	......	93	94	105	93	83	±10.6
Corn:										
Plot B	23.5	0.0	0.0	29.7	6.5	0.0	53.0	31.2	18.0	
Plot E	20.8	0.0	0.0	26.3	9.4	0.0	47.7	32.3	17.1	
Ratio of E to mean	94	......	......	94	118	......	95	102	101	± 3.2

Table IV presents eight years' results with spring wheat, winter wheat, oats, barley, and corn. During these years conditions have ranged from the drouth of 1911, which was so severe that all crops on all methods of preparation were total failures, to the favorable conditions of 1915, when the highest yields of spring grains yet recorded in experimental work in the Great Plains were obtained.

Of the 40 comparisons offered, only 11 are in favor of subsoiling. These are so evenly distributed throughout the different crops and years that no positive conclusion can be derived from them. A negative conclusion that subsoiling has afforded no protection against drouth is very clearly indicated. In the average of the eight years the differences in yield as a result of the two methods are measured in fractions of a bushel with every crop. The departures of the average ratios from 100 are all less than the probable error except in the case of barley, where the departure is less than twice the probable error. With this crop the difference in average number of bushels per acre is in one direction, while the departure of the average ratios is in the other. This is partly explained by the fact that in 1910 there was a production of nearly 5 bushels per acre on the fall plowing, while the subsoiled plot was a total failure. The mean ratio of all crops is 98, with a probable error of 2.5 This shows practically no effect in either direction as an average result of subsoiling.

ARDMORE FIELD STATION

The soil on the Ardmore (S. Dak.) Field Station is a heavy clay loam with a lighter subsoil. The subsoil is not uniform, but at depths of 3 feet or more it generally breaks into sand or gravel.

Three years' results, exclusive of the year 1914, when the crop was completely destroyed by hail, are available for study. One year the crops from many methods, including the two under study, were total failures. One year the yields were good, and one year the yields were very high.

Table V presents in detail the results with spring wheat, winter wheat, oats, barley, and corn at this station. With all crops except winter wheat, with which the better yield both years has been from subsoiling, the evidence is all against that practice. It failed with all crops to overcome the drouth of 1913, and actually appeared to reduce the yields of all crops but winter wheat both in the exceptionally productive year of 1915 and in the more normal year of 1916. The average ratio of all crops is 93, with a probable error of 3.1. There apparently is at this station a detrimental effect from subsoiling. The decrease in yield is not, however, enough greater than its probable error to make it all certain that it might not be effaced by continuation of the record.

TABLE V.—*Yields at the Ardmore (S. Dak.) Field Station of spring wheat, winter wheat, oats, barley, and corn each year from 1913 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Crop and plot.	Yield or ratio.					
	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:						
Plot B	0.0	(a)	49.5	17.5	22.3	
Plot E	0.0	(a)	43.3	12.8	18.7	
Ratio of E to mean			93	84	89	±3.8
Winter wheat:						
Plot B	0.0	(a)	29.2	29.8	19.7	
Plot E	0.0	(a)	33.3	34.5	22.6	
Ratio of E to mean			107	107	107	± .0
Oats:						
Plot B	0.0	(a)	75.4	42.2	39.2	
Plot E	0.0	(a)	59.4	25.0	28.1	
Ratio of E to mean			88	74	81	±5.9
Barley:						
Plot B	0.0	(a)	54.0	25.2	26.4	
Plot E	0.0	(a)	51.0	24.7	25.2	
Ratio of E to mean			97	99	98	±0.8
Corn:						
Plot B	0.0	0.0	43.7	28.7	18.1	
Plot E	0.0	0.0	32.9	26.6	14.9	
Ratio of E to mean			86	96	91	±4.2

[a] Crop destroyed by hail.

SCOTTSBLUFF FIELD STATION

The soil of the Scottsbluff (Nebr.) Field Station is a comparatively light sandy loam. At a depth varying from 5 to 8 feet there is a sharp break from this soil to either sand or Brule clay. Above this point the soil offers no unusual resistance either to the downward passage of water or to the development of roots.

Table VI presents five years' results with spring wheat, oats, barley, and corn at this station. Considered either by crops or by years, the only consistency to be noted is the heavier production on the subsoil plots in 1912. In the average of the five years the differences exhibited are very small and are less than the probable error with all crops except barley, where the difference only slightly exceeds the probable error.

TABLE VI.—*Yields at the Scottsbluff (Nebr.) Field Station of spring wheat, oats, barley, and corn each year from 1912 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield of B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Crop and plot.	Yield or ratio.						
	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:							
Plot B	6.3	7.8	6.7	16.2	5.7	8.5	
Plot E	12.3	6.3	9.5	6.8	7.0	8.4	
Ratio of E to mean	132	89	117	59	110	101	±9.3
Oats:							
Plot B	21.6	16.9	14.7	39.7	7.2	20.0	
Plot E	27.8	17.5	15.9	48.1	2.8	22.4	
Ratio of E to mean	113	102	104	110	56	97	±6.9
Barley:							
Plot B	23.5	....	4.4	35.4	10.0	18.3	
Plot E	24.8	....	5.2	26.0	6.0	15.5	
Ratio of E to mean	103	....	108	85	75	93	±6.2
Corn:							
Plot B	38.0	32.2	20.1	10.1	22.1	24.5	
Plot E	40.0	26.1	14.2	13.6	23.2	23.4	
Ratio of E to mean	103	90	83	115	102	99	±4.1

ARCHER FIELD STATION

The soil of the field station at Archer, Wyo., is a medium-dark sandy loam with a little fine gravel distributed very evenly through it. Below the second foot the proportion of sand increases, and at a depth varying from 3 to 6 feet pure gravel is reached.

Table VII presents three years' results with spring wheat, winter wheat, and oats, and two years' results with corn and barley at this station. Of the 13 comparisons afforded only 5 appear to be in favor of subsoiling. Only with corn has the heavier yield for more than one year been from the subsoiled plot. The average differences exhibited by all crops are insignificant when considered in connection with the probable error.

TABLE VII.—*Yields at the Archer (Wyo.) Field Station of spring wheat, winter wheat, oats, barley, and corn each year from 1914 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yield of corn in pounds of stover; other crops in bushels of grain per acre]

Crop and plot.	Yield or ratio.				
	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:					
Plot B	7.5	23.7	2.4	11.2	
Plot E	5.8	25.0	1.0	10.6	
Ratio of E to mean	87	103	59	83	± 9.6
Winter wheat:					
Plot B	0.0	24.7	7.4	10.7	
Plot E	0.0	24.2	2.4	8.9	
Ratio of E to mean	....	99	49	74	±21.1
Oats:					
Plot B	14.5	35.9	3.7	18.0	
Plot E	9.4	34.7	5.6	16.6	
Ratio of E to mean	79	98	120	99	± 8.4
Barley:					
Plot B	....	29.8	5.2	17.5	
Plot E	....	35.8	4.2	20.0	
Ratio of E to mean	....	109	89	99	± 8.5
Corn:					
Plot B	1,090	3,900	(a)	2,495	
Plot E	1,130	4,450	(a)	2,790	
Ratio of E to mean	102	107	....	105	± 2.1

[a] Weights lost.

AKRON FIELD STATION

The soil of the field station at Akron, Colo., is a clay loam locally known as "hard land." It is characterized in the native vegetation by a growth of short grass.

Table VIII presents an unbroken record of eight years' results with spring wheat, oats, barley, and corn, and seven years' results with winter wheat at this station. The E plots were subsoiled in the fall of 1908, 1909, 1812, 1913, and 1914. Of the 39 comparisons presented in this table only 7 show the higher yields from the subsoiled plot. The only consistency in the distribution of these among the different crops or years is that in 1909 all four crops under trial that year showed the heavier yield on the subsoiled plot. In the average of the eight years the better yield of each crop has been obtained from the plot not subsoiled. The average decrease in yield as a result of subsoiling ranges from 1.7 bushels per acre with winter wheat to 3.4 bushels per acre with corn. The average ratio for all crops is 85. This station shows the clearest cut and most decisive results of any station where subsoiling has been investigated.

TABLE VIII.—*Yields at the Akron (Colo.) Field Station of spring wheat, winter wheat, oats, barley, and corn each year from 1909 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Crop and plot.	Yield or ratio.									
	1909	1910	1911	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:										
Plot B.....	10.3	6.2	4.1	20.7	0.8	12.2	25.8	3.8	10.5	
Plot E.....	11.2	5.5	1.5	16.0	.5	9.8	23.7	1.7	8.7	
Ratio of E to mean..	104	94	54	87	77	89	96	62	83	±4.4
Winter wheat:										
Plot B.....	......	10.3	6.8	26.7	2.0	24.8	20.8	4.2	13.7	
Plot E.....	......	6.9	3.3	21.2	3.2	24.5	21.0	3.8	12.0	
Ratio of E to mean..	......	80	65	89	123	99	100	95	93	±4.4
Oats:										
Plot B.....	14.1	8.0	15.9	46.9	.6	36.9	57.2	7.2	23.4	
Plot E.....	16.1	11.3	8.4	35.3	0.0	30.3	57.5	4.1	20.4	
Ratio of E to mean..	107	117	69	86	0.0	90	100	73	80	±7.9
Barley:										
Plot B.....	16.8	10.5	16.3	27.9	3.1	36.7	47.9	5.0	20.5	
Plot E.....	19.8	6.9	5.2	22.5	1.5	27.9	52.3	4.2	17.5	
Ratio of E to mean..	108	79	48	89	65	86	104	91	84	±4.7
Corn:										
Plot B.....	27.3	18.3	0.0	46.9	9.9	17.3	29.2	4.8	19.2	
Plot E.....	32.8	12.7	0.0	37.1	4.3	13.9	22.3	3.2	15.8	
Ratio of E to mean..	109	82	......	88	61	89	87	80	85	±3.2

HAYS FIELD STATION

The soil of the field station on which the experimental work has been conducted at Hays, Kans., is a heavy silt loam. Penetration of water to the lower depths is slow, the very compact soil in the third foot offering marked resistance to its downward passage.

Table IX presents from this station a record beginning with 1907 for winter wheat and corn; 1908 for spring wheat, oats, and barley; 1911 for kafir; and 1912 for milo. In the average of all the years the higher yields are from the subsoiled plots with all crops except barley, which shows no difference. With corn the higher yield has been obtained every year from the subsoiled plot. Winter wheat, corn, and kafir show increases amounting to more than three times the probable error. With the other crops the differences are less than the probable error. This is the only station at which the averages of all crops show a ratio of 100 or more on the subsoiled plot. With some of the crops the average yields have been so small as to be unprofitable from either method. It should be noted that this station has the highest annual precipitation of any station under study. As noted later in discussing the use of dynamite and deep plowing, the results of those practices do not support those obtained from subsoiling.

TABLE IX.—*Yields at the Hays (Kans.) Field Station of spring wheat, winter wheat, oats, barley, corn, kafir, and milo each year from 1907 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of all crops in bushels per acre]

Crop and plot.	Yield or ratio.											
	1907	1908	1909	1910	1911	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:												
Plot B	......	4.5	(a)	9.6	0.0	15.2	0.5	(b)	7.0	0.7	5.4	
Plot E	......	5.2	(a)	12.6	0.0	12.7	1.3	(b)	8.3	.3	5.8	
Ratio of E to mean	......	107	......	114	......	91	144	......	108	60	104	±7.2
Winter wheat:												
Plot B	18.2	23.2	(a)	27.8	.3	13.8	2.3	24.8	13.1	22.7	16.2	
Plot E	13.6	30.5	(a)	39.8	.3	20.1	4.1	25.3	14.9	27.6	19.6	
Ratio of E to mean	86	114	......	118	100	119	128	101	106	110	109	±2.9
Oats:												
Plot B	......	3.7	(a)	16.6	0.0	37.7	10.6	27.0	25.1	6.0	15.8	
Plot E	......	17.9	(a)	24.5	0.0	45.1	21.8	26.6	29.2	1.0	20.8	
Ratio of E to mean	......	166	......	119	......	109	135	99	108	29	109	±9.1
Barley:												
Plot B	......	12.4	(a)	19.7	0.0	28.8	4.0	16.7	26.8	10.1	14.8	
Plot E	......	14.8	(a)	19.3	0.0	33.8	4.6	15.2	22.4	8.2	14.8	
Ratio of E to mean	......	109	......	99	......	108	107	95	91	90	100	±2.4
Corn:												
Plot B	12.2	3.1	7.9	6.8	(c)	1.8	(c)	5.5	14.9	3.6	7.0	
Plot E	13.6	8.8	8.0	7.4	(c)	5.5	(c)	6.4	16.5	4.3	8.8	
Ratio of E to mean	105	148	101	104	......	151	......	108	105	109	116	±5.2
Kafir:												
Plot B	......	......	......	......	.6	12.8	(c)	16.3	67.4	.4	19.5	
Plot E	......	......	......	......	1.0	26.1	(c)	23.0	66.6	.7	23.5	
Ratio of E to mean	......	......	......	......	125	134	......	117	99	127	120	±4.2
Milo:												
Plot B	......	......	......	......	(c)	16.2	(c)	15.2	53.5	1.4	21.6	
Plot E	......	......	......	......	(c)	17.5	(c)	17.6	48.8	1.3	21.3	
Ratio of E to mean	......	......	......	......	......	104	......	107	95	96	101	±2.4

[a] Destroyed by hail. [b] Destroyed by soil blowing. [c] Destroyed by insects.

GARDEN CITY FIELD STATION

The work at the field station at Garden City, Kans., is on a high upland. The soil is a light silt loam. With the exception of the accumulated humus near the surface it is practically uniform to a depth of at least 15 feet. The development of roots is limited only by the depth to which water is available and the physiological character of the plant.

Table X presents the results of seven years' work at this station, exclusive of 1913, when the crops were destroyed by hail. In 1911, which is included in the averages, all small-grain crops failed from drought so extreme that it was not overcome by any method under trial. In 1914 the higher yield of all five crops under trial was on the subsoiled plot. This was the only year, however, when there was a consistent, marked difference in the results from the two methods. With none of the five crops has the average departure in either direction from the mean been greater than 4 per cent. Only in the case of wheat, which has a mean ratio of 103, with a probable error of 2.5, is the departure from the mean greater than the probable error. The results are conclusive in showing that subsoiling is without significant effect at this station.

TABLE X.—*Yields at the Garden City (Kans.) Field Station of spring wheat, winter wheat, oats, barley, and corn each year from 1909 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yield of corn in total pounds; other crops in bushels per acre]

Crop and plot.	Yield or ratio.									
	1909	1910	1911	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:										
Plot B	3.2	5.2	0.0	6.3	(a)	4.3	12.6	0.0	4.5	
Plot E	2.9	5.2	0.0	7.7	(a)	5.3	12.0	0.0	4.7	
Ratio of E to mean	95	100	......	110	......	110	98	......	103	±2.5
Winter wheat:										
Plot B	0.0	0.0	0.0	0.0	(a)	6.3	10.0	0.0	2.3	
Plot E	0.0	0.0	0.0	0.0	(a)	6.7	9.9	0.0	2.4	
Ratio of E to mean	......	......	......	......	......	103	99	......	101	±1.7
Oats:										
Plot B	3.2	10.3	0.0	23.1	(a)	8.1	32.7	3.0	11.5	
Plot E	2.6	10.0	0.0	15.9	(a)	17.3	30.9	3.0	11.4	
Ratio of E to mean	90	99	......	82	......	136	97	100	101	±4.5
Barley:										
Plot B	4.8	5.4	0.0	9.0	(a)	15.2	24.2	3.0	8.8	
Plot E	3.7	5.2	0.0	8.5	(a)	17.3	21.5	4.0	8.6	
Ratio of E to mean	87	98	......	97	......	106	94	114	99	±2.6
Corn:										
Plot B	(b)	(b)	1,400	4,620	(a)	3,040	1,900	1,200	2,440	
Plot E	(b)	(b)	750	4,500	(a)	4,840	1,800	2,260	2,830	
Ratio of E to mean	......	......	70	99	......	123	97	131	104	±7.8

[a] Crop destroyed by hail. [b] Weights lost.

AMARILLO FIELD STATION

The soil at the field station at Amarillo, Tex., is a heavy clay silt. The storage of water and the development of the feeding roots of the crop are apparently interfered with by comparatively impervious soil in the third foot.

Eight years' results with spring wheat, winter wheat, oats, and barley, and nine years' with corn are presented in Table XI. The year 1910 is not included, as the location of the station was changed, and the preparation of the land was uniform for that year. Of the 41 comparisons afforded in this table less than one-third show the higher yield to have been from the subsoiled plot. There is no consistency in the distribution of these either by years or by crops. In the average of the entire period the results with all crops are against subsoiling. The average decrease in yields as a result of subsoiling ranges from 1 bushel per acre with spring wheat to 3.2 bushels with oats. With all crops except corn the decrease due to subsoiling is more than twice the probable error.

TABLE XI.—*Yields at the Amarillo (Tex.) Field Station of spring wheat, winter wheat, oats, barley, and corn each year from 1907 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yield of all crops in bushels per acre]

Crop and plot.	Yield or ratio.										
	1907	1908	1909[a]	1911	1912	1913	1914	1915	1916	Average.	Probable error of mean ratio.
Spring wheat:											
Plot B	....	14.0	2.8	10.0	8.5	1.8	12.8	11.0	7.0	8.5	
Plot E	....	16.2	4.0	11.3	4.2	.8	12.3	10.3	1.2	7.5	
Ratio of E to mean	....	107	118	106	66	62	98	97	29	85	±7.9
Winter wheat:											
Plot B	....	14.3	0.0	3.5	7.2	1.3	23.0	24.4	3.6	9.7	
Plot E	....	16.5	0.0	1.2	3.3	1.3	19.3	19.7	4.5	8.2	
Ratio of E to mean	....	107	....	51	63	100	91	89	111	87	±6.1
Oats:											
Plot B	....	32.2	0.0	27.5	14.1	2.5	30.9	31.7	12.2	18.9	
Plot E	....	28.1	0.0	19.2	8.8	4.1	30.6	34.2	.9	15.7	
Ratio of E to mean	....	93	....	82	77	124	100	104	14	85	±8.0
Barley:											
Plot B	....	13.2	5.8	11.7	1.7	0.0	16.7	17.3	3.8	8.8	
Plot E	....	11.9	0.0	10.3	1.5	0.0	17.1	16.0	.2	7.1	
Ratio of E to mean	....	95	0.0	94	94	....	101	96	10	70	±12.0
Corn:											
Plot B	1.4	22.9	2.7	9.2	.7	0.0	3.6	54.0	7.2	11.3	
Plot E	1.1	25.7	1.7	7.1	1.0	0.0	5.1	46.4	3.7	10.2	
Ratio of E to mean	88	106	77	87	118	....	117	92	68	94	±4.7

[a] No record for 1910 on account of change in location of station.

TUCUMCARI FIELD STATION

The soil of the field station at Tucumcari, N. Mex., is of a residual type and is classified by the Bureau of Soils as a fine sand. The sand extends down to a depth of from 1 to 3 feet, gradually blending into a clay which continues in many places to a depth of at least 135 feet.

Table XII presents three years' results with kafir, milo, sorghum, broom corn, and cotton at this station. Of the 15 comparisons afforded in this table only 2 are in favor of subsoiling. These are kafir in 1914 and broom corn in 1915. This evidence seems conclusive that subsoiling here is at least an unnecessary if not a detrimental practice.

TABLE XII.—*Yields at the Tucumcari (N. Mex.) Field Station of kafir, milo, sorghum, broom corn, and cotton each year from 1914 to 1916, inclusive, on plot E, subsoiled, and plot B, not subsoiled but otherwise similarly treated, together with the average of each method for the entire period of years; the ratio of the yield on E to the mean of the yield on B and E each year; the mean ratio; and the probable error of the mean ratio*

[Yields of kafir and milo in bushels; sorghum in pounds of forage; broom corn in pounds of brush; and cotton in pounds of seed cotton per acre]

Crop and plot.	Yield or ratio.				
	1914	1915	1916	Average.	Probable error of mean ratio.
Kafir:					
Plot B	34.9	39.8	18.0	30.9	
Plot E	38.5	39.8	18.0	32.1	
Ratio of E to mean	105	100	100	102	±1.4
Milo:					
Plot B	45.8	46.8	9.0	33.9	
Plot E	36.2	41.1	7.2	28.2	
Ratio of E to mean	88	94	89	90	±1.4
Sorghum:					
Plot B	5,320	5,020	5,560	5,300	
Plot E	5,080	4,980	4,600	4,887	
Ratio of E to mean	98	100	91	96	±2.2
Broom corn:					
Plot B	583	500	420	501	
Plot E	490	780	190	487	
Ratio of E to mean	91	122	62	92	±12.2
Cotton:					
Plot B	838	520	380	579	
Plot E	773	340	205	439	
Ratio of E to mean	96	79	70	82	± 5.8

COMPARATIVE RESULTS WITH SUBSOILING DIFFERENT CROPS

The comparative results with different crops as shown in Table XIII and figures 2 and 3 scarcely warrant any conclusion that one crop is affected differently than another by subsoiling. The average ratios with spring wheat, winter wheat, oats, and barley, which range from 94 to 97, with probable errors ranging from 2 to 2.6, certainly do not indicate any difference in the relative effect of subsoiling upon these crops. Corn

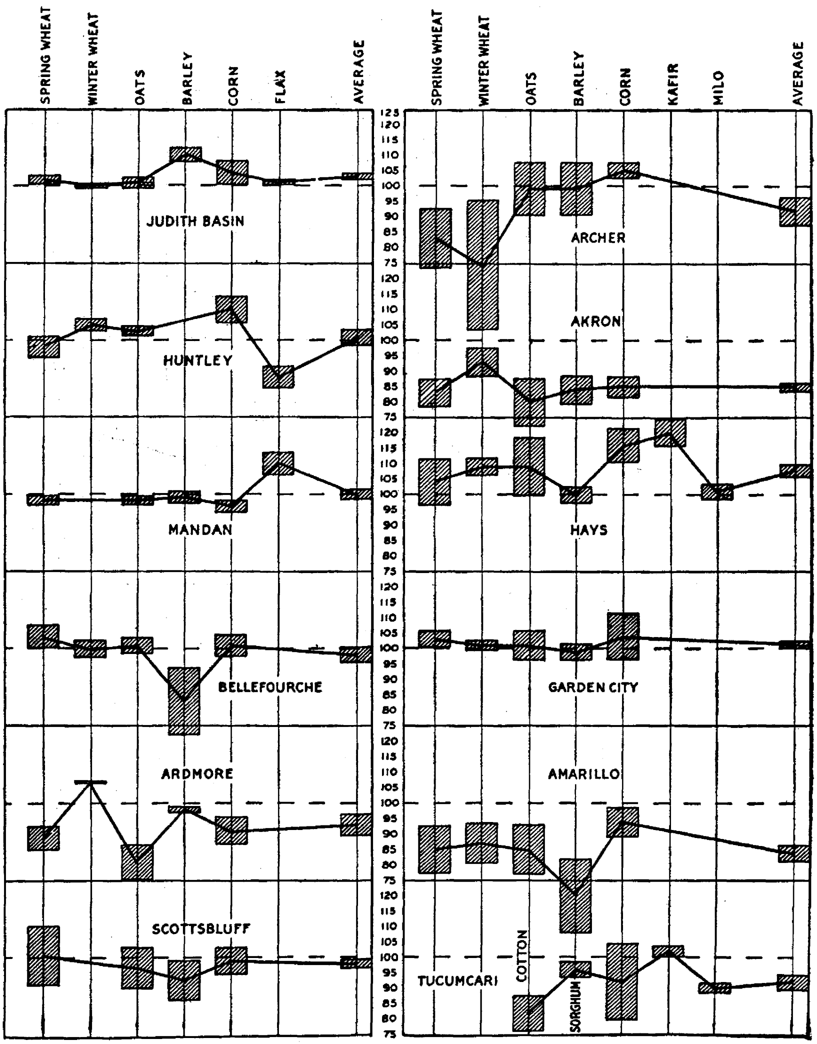

FIG. 2.—Ratio of the yield for each crop at each station of plot E (subsoiled) to the mean of the yield of plot B (not subsoiled) and plot E (subsoiled) and the averageof all crops at each station. The shaded areas are delimited by the probable error of each ratio. They mark the zones within which the chances are even that the results of a repetition of the experiments would fall.

at the same stations has a ratio of 100, with a probable error of 1.8. While the difference between this and the other crops is not great enough to make it in any way conclusive, it might perhaps indicate a slightly better response from this crop.

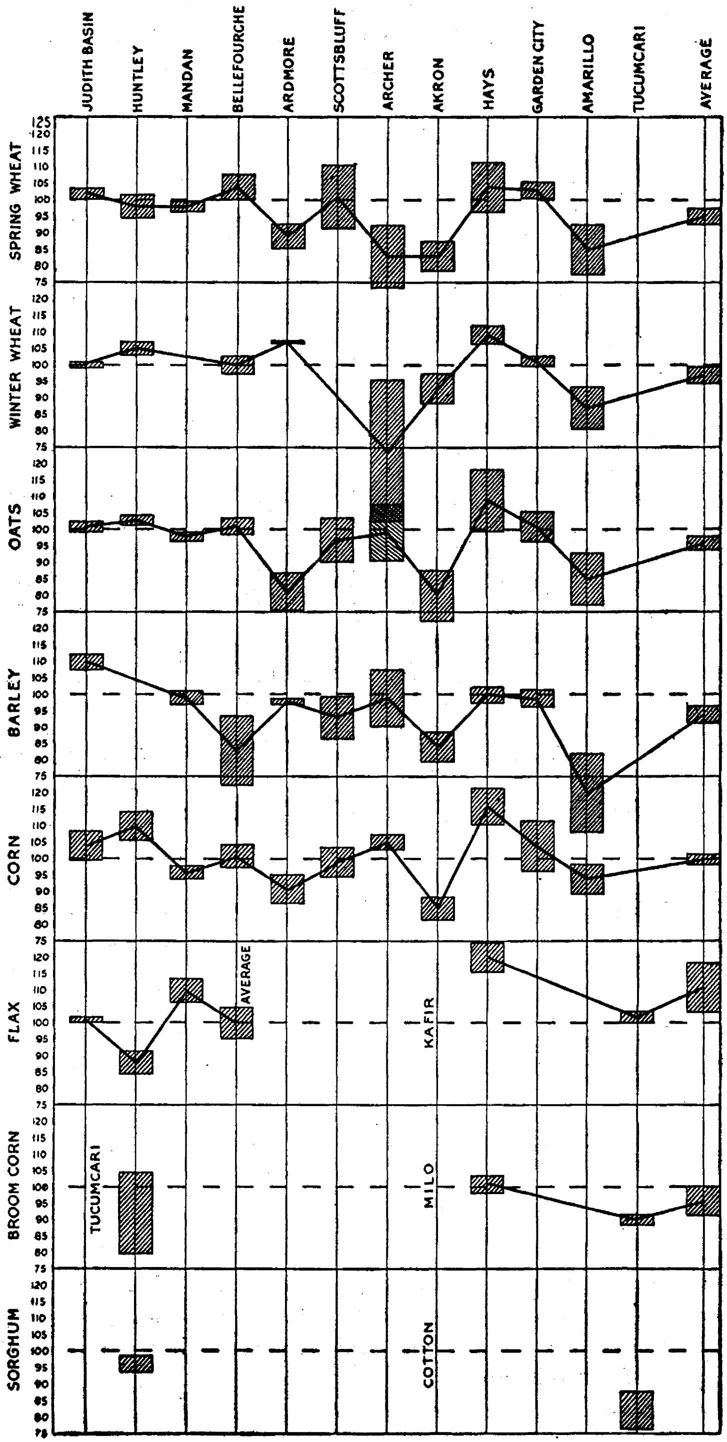

FIG. 3.—Ratio of the yield for each crop at each station of plot E (subsoiled) to the mean of the yield of plot B (not subsoiled) and plot E (subsoiled) and the average of each crop at all stations. The shaded areas are delimited by the probable errors. They mark the zones within which the chances are even that the results of a repetition of the experiments would fall.

When studied by the number of trials that resulted either in favor of or against subsoiling, it was found that, while with oats, corn, and winter wheat slightly more than half the trials resulted in favor of subsoiling and with spring wheat and barley slightly less than half, the deviations were not enough greater than their probable errors to make them significant.

The effect upon flax is apparently not different from that on the small-grain crops.

TABLE XIII.—*Summary table showing mean ratio*[a] *and probable error of mean of each crop at each station as shown in Tables I to XII, inclusive, and the general mean for each crop at all stations, and of all crops at each station*

Crop and factor.	Judith basin.	Huntley.	Mandan.	Bellefourche.	Ardmore.	Scottsbluff.	Archer.	Akron.	Hays.	Garden City.	Amarillo.	Tucumcari.	Mean and probable error.
Spring wheat:													
Ratio	102	98	98	104	89	101	83	83	104	103	85	......	95±2.1
Probable error±	1.3	3.4	1.6	3.8	3.8	9.3	9.6	4.4	7.2	2.5	7.9	......	
Winter wheat:													
Ratio	100	105	......	100	107	......	74	93	109	101	87	......	97±2.6
Probable error±	.9	2.0	......	2.9	0.0	......	21.4	4.4	2.9	1.7	6.1	......	
Oats:													
Ratio	101	103	98	101	81	97	99	80	109	101	85	......	96±2.0
Probable error±	1.9	1.5	1.3	2.3	5.9	6.9	8.4	7.9	9.1	4.5	8.0	......	
Barley:													
Ratio	110	......	99	83	98	93	99	84	100	99	70	......	94±2.5
Probable error±	2.2	......	2.0	10.6	0.8	6.2	8.5	4.7	2.4	2.6	12.0	......	
Corn:													
Ratio	104	110	96	101	91	99	105	85	116	104	94	......	100±1.8
Probable error±	4.2	4.1	2.0	3.2	4.2	4.1	2.1	3.2	5.2	7.8	4.7	......	
Flax:													
Ratio	101	88	110	......	......	......	......	......	......	......	......	......	100±4.6
Probable error±	.9	3.7	3.4	......	......	......	......	......	......	......	......	......	
Kafir:													
Ratio	......	......	......	......	......	......	......	......	120	......	......	102	111±7.6
Probable error±	......	......	......	......	......	......	......	......	4.2	......	......	1.4	
Milo:													
Ratio	......	......	......	......	......	......	......	......	101	......	......	90	96±4.6
Probable error±	......	......	......	......	......	......	......	......	2.4	......	......	1.4	
Broom corn:													
Ratio	......	......	......	......	......	......	......	......	......	......	......	92	
Probable error±	......	......	......	......	......	......	......	......	......	......	......	12.2	
Sorghum:													
Ratio	......	......	......	......	......	......	......	......	......	......	......	96	
Probable error±	......	......	......	......	......	......	......	......	......	......	......	2.2	
Cotton:													
Ratio	......	......	......	......	......	......	......	......	......	......	......	82	
Probable error±	......	......	......	......	......	......	......	......	......	......	......	5.8	
Mean ratio	103	101	100	98	93	98	92	85	108	102	84	92	
Probable error..±	1.0	2.6	1.6	2.5	3.1	1.2	4.6	1.4	2.0	.7	2.5	2.2	

[a] Ratio based on yields of crops at the different stations as follows: Seed cotton, broom-corn brush, and sorghum forage at Tucumcari; corn stover at Judith Basin, Archer, and Garden City; ear corn at Huntley, Mandan, Bellefourche, Ardmore, Scottsbluff, Akron, Hays, and Amarillo; all other crops on yields of grain at all stations.

Kafir at the two stations from which results with this crop have been obtained appears to have given a markedly favorable response to subsoiling in comparison with the effect of that practice upon other crops, particularly milo. This subject is being given much fuller investigation at a number of additional stations to which the crop is adapted.

The results with sorghum, cotton, and broom corn being from a single station can scarcely be compared with those obtained with other crops.

The grand average ratio of all crops at all stations is 97, with a probable error of 0.9. This average, of course, is meaningless in its possible application to any crop or any station. It would be influenced by the distribution of the observations among conditions that were either favorable or unfavorable in their response. The only purpose of introducing it here is to show the relative lack of any effect, and particularly of any favorable effect, of the practice of subsoiling as applying to a wide territory and a wide range of crops.

This lack of effect of the practice when applied generally to all crops and to the entire area is further confirmed when the results are studied in another way. Exclusive of years of total failure there are 353 trials here reported. In 15 of these there was no difference in the yield from the two methods, in 153 cases the higher yield was obtained from the subsoiled plot, and in 185 cases from the plot not subsoiled.

COMPARATIVE RESULTS WITH SUBSOILING IN FAVORABLE AND UNFAVORABLE YEARS

The relative effect of subsoiling in favorable and unfavorable years is a question that naturally arises. There have been a number of cases in which the crops by both methods have been a total failure. *There have been some cases in which the plot not subsoiled produced a small crop when the subsoiled plot was a total failure. There has been no case in the history of the experiments when the reverse was true.* In order to obtain definite information on the subject the results were divided into two groups; one group containing the ratios from each station for those years when the yield was above the average for that station and the other group containing the ratios of those years when the yield was below the average. Those groups showed average ratios of 100 for the years of better production and 94.4 for the years of poorer production.

In the years above the average in production 75 trials resulted in favor of subsoiling, 81 trials in favor of ordinary plowing, and in 8 trials the same yield was obtained from each method. In the years below the average in production 78 trials resulted in favor of subsoiling, 104 in favor of ordinary plowing, and 7 showed no difference in the yields from the two methods.

These results indicate that, on the average, subsoiling, instead of overcoming the effects of drouth, actually intensifies them. In this connection it should be recognized that, while low yields are in some cases caused by fungus diseases, by insect attacks, or by unfavorable temperature or other weather conditions, the one primary predominating cause of low yields has been the lack of sufficient soil moisture at some time during the growth of the crop.

DEEP TILLING BY THE USE OF DYNAMITE OR SPECIAL PLOWS

Experiments have been conducted with both dynamite[1] and the Spalding deep-tilling machine at the Hays and Akron stations, and with dynamite at the Ardmore, Bellefourche, and Judith Basin stations.

HAYS FIELD STATION

DEEP TILLING BY THE USE OF DYNAMITE AND SPECIAL PLOWS

In 1913 a series of experiments was started at Hays, Kans., to determine the effect of different methods of preparing the land for winter wheat in a series of three-year rotations of fallow, winter wheat, and kafir. In this series four rotations, No. 501, 502, 503, and 504, are identical except as noted below. In No. 501 the plowing for the fallow is done with a Spalding deep-tilling machine, which plows the soil to a depth of from 12 to 14 inches. This plowing is done in the fall, preceding the fallow season, or practically an entire year before seeding to winter wheat. In rotation 502, dynamite is used in the fall. After dynamiting, the land is furrowed with a lister, the same as in rotations 503 and 504. In dynamiting, 18 shots of half sticks of 20 per cent powder placed 3 feet deep are fired on the tenth-acre plot, the distance between the shots being 16 feet. The plots to be fallowed in rotations 503 and 504 are furrowed out with the lister in the fall preceding the fallow season. These two rotations are identical except that the wheat stubble in No. 503 is disked after harvest, while that in No. 504 receives no cultivation until both are furrowed with a lister in the fall. All the fallow plots are given necessary cultivation to keep them free from vegetation during the fallow year. These rotations were begun in the spring of 1913, but the crops that year were a failure. The first dynamiting and deep tilling was done in the fall or 1913. The land so treated was fallow in 1914, so the first crop of wheat on plots differing in their treatment was harvested in 1915. The first kafir following the wheat on the plots differently treated was produced in 1916.

In Table XIV are given the yields of both winter wheat and kafir for the three years 1914, 1915, and 1916. There are thus shown one wheat crop, 1914, on land uniform in preparation, and two wheat crops, 1915 and 1916, on land differing in its treatment. With the kafir crop the preparation of the various rotations was uniform for the crops of 1914 and 1915, but was differentiated for the crop of 1916. To facilitate comparisons, the data in this table are shown in two forms. First, the yield in bushels, and second, the ratio of these yields to the mean yield of the four plots for each year. The data from plots differing in their treatment are shown in boldfaced type.

[1] The E. I. du Pont de Nemours Powder Co. furnished the material for the dynamiting experiments and experts to direct the operations at the different field stations.

It appears from these results that no significant differences in the yields have resulted from the differences in preparation. There are no greater differences exhibited between the deep-tilled or dynamited plots and those not so treated than are shown between the same plots when the preparation of the land was uniform, or are shown between rotations 503 and 504, which are practically the same in their treatment.

TABLE XIV.—*Yields at the Hays (Kans.) Field Station for the years 1914 to 1916, inclusive, from four 3-year rotations of fallow, winter wheat, and kafir, showing the results of dynamiting and deep tillage of fallow*

Rotation and crop.	Yield in bushels.			Ratio of yield to mean.		
	1914	1915	1916	1914	1915	1916
Rotation 501:						
Fallow, deep-tilled	......	......	......	......	......	......
Winter wheat	24.8	14.9	38.8	98	108	107
Kafir	2.6	51.2	12.7	52	104	105
Rotation 502:						
Fallow, dynamited	......	......	......	......	......	......
Winter wheat	24.3	13.5	32.9	96	98	91
Kafir	5.0	46.4	9.5	100	94	79
Rotation 503:						
Fallow, listed	......	......	......	......	......	......
Winter wheat	25.5	14.4	35.5	100	104	98
Kafir	6.4	46.8	11.4	128	93	94
Rotation 504:						
Fallow, listed	......	......	......	......	......	......
Winter wheat	26.9	12.5	37.8	106	91	104
Kafir	5.9	52.2	14.7	118	106	121

AKRON FIELD STATION

DEEP TILLAGE BY THE USE OF DYNAMITE

At the field station at Akron, Colo., a square of prairie sod was divided checkerboard fashion into 16 plots each 4 rods square, separated by the necessary alleys, making 0.1 acre in each plot. The designation of the plots by letters is similar to that at Ardmore (fig. 4). On August 26 and 27, 1912, the two center tiers of plots running north and south were dynamited. The soil was quite dry at this time. Twenty per cent dynamite was used, the shots being placed 15 feet apart, 16 holes to the plot. The shots were fired at a depth of 30 inches, ½ pound of dynamite being used for each charge. After a rain which put the soil in good condition the entire block of plots was broken, September 16 to 18, and the sod rolled flat with a roller.

In the spring of 1913 the eight plots on the north, four of which had been dynamited and four of which had not, were given the necessary disking and harrowing to make as good a seed bed as possible, and were then seeded to durum wheat. The eight plots composing the two tiers on the south side of the block were replowed and the seed bed prepared with the disk and harrow. These eight plots were planted to corn.

The season proved very dry, and both crops were a failure on all plots. The late breaking was not considered a favorable preparation because of the lack of water in storage in the soil. Under favorable conditions of spring and summer rainfall it would have produced a crop, but under the conditions that actually obtained only failure was to be expected.

No effect of the blasting could be observed in the crop. Where a charge of dynamite had been set, there was a slight depression and the wheat in this space was an inch or two taller than that surrounding it, but no taller than it was in other depressions not caused by blasting.

The wheat plots were plowed 5 inches deep on September 23. The corn plots were plowed 5 inches deep on July 15, when the corn was so badly damaged by drought that it was evident there would be no crop produced. The same plots were replanted to wheat and corn in 1914. The yields are given in Table XV. The difference between the average yield of wheat on the four plots dynamited and on the four plots not dynamited is well within the probable error of the series. The average yield of corn on the plots not dynamited was 14.1 bushels, with a probable error of 1.5 bushels, while on the dynamited plots the average yield was 18.6 bushels, with a probable error of 1.3 bushels. Even the apparent increase in yield, which the probable error shows is open to question that it may have been due to accidental causes, is in no way commensurate with the expense of dynamiting, even if the effect persisted for a number of years.

TABLE XV.—*Yields of wheat and corn (bushels per acre) in 1914 at the Akron (Colo.) Field Station on land dynamited in 1912, and on control plots not dynamited*

Crop and treatment.	Plot and yield.				Average.	Probable error.
Wheat:						
Not dynamited	A 17.8	C 15.7	K 13.0	M 15.3	15.5	±0.6
Dynamited	B 14.4	D 16.1	J 14.0	L 15.6	15.0	±0.4
Corn:						
Not dynamited	E 17.6	G 10.4	O 11.6	Q 16.7	14.1	±1.5
Dynamited	F 13.4	H 20.0	N 18.9	P 22.2	18.6	±1.3

In 1915 the eight plots constituting the west half of the block were planted to corn and the eight plots constituting the east half to wheat. The average yield of ear corn was 33.2 bushels per acre. The average yield of the four plots dynamited in the fall of 1912 was exactly the same as that of the four not dynamited. The individual yields of the four wheat plots following wheat were lost by mixture. There was no difference in height, stand, or estimated yield. Of the four wheat plots following corn two were dynamited in 1912. Their yield was 18.2 bushels on plot J and 19.2 bushels on plot L. Plot K, not dynamited, yielded 16.2 bushels, and plot M, not dynamited, 18.2 bushels. This shows an average gain of 1.5 bushels per acre in favor of the pair of dynamited plots, but exactly the same difference is shown between the pairs J–K and L–M that do not differ in their treatment.

The experiment was continued in 1916 by seeding the north half to corn and the south half to wheat as in 1914. The season proved unfavorable, and these plots were badly damaged by rabbits. As no differences were apparent that could be attributed to the use of the dynamite, the yields were not determined.

DEEP TILLAGE BY THE USE OF SPECIAL PLOWS

The land used in the deep-tillage experiment is a block 37 rods long north and south and 10 rods wide, divided into 16 plots 10 rods long and 2 rods wide containing ⅛ acre each. Bare, cultivated alleys 4 feet 7 inches wide separate the plots. The land was broken from prairie sod during the summer of 1907, but a record of its treatment for the seasons of 1908 and 1909 is not available. During the season of 1910 the west half of all the plots produced a light crop of oats, and the east half was planted to cultivated crops of corn, sorghum (*Andropogon sorghum*), and sunflowers (*Helianthus annuus*). The soil is a sandy loam, increasing in heaviness toward the north. The north half of the block slopes slightly to the north. The 16 plots are designated by the letters A to Q, reading from the south.

In the spring of 1911 an experiment was outlined to test the effect of deep tillage, as compared with ordinary plowing, for spring wheat and corn in different combinations of wheat and corn and the two tillage depths. Eight of the sixteen plots were to be deep-tilled and eight plowed in the ordinary manner each year; eight plots to be cropped to wheat and eight to corn in such manner as to afford different combinations of these crops and tillage methods.

The Spalding deep-tilling machine used in this experiment was received too late to prepare for wheat in 1911. The eight plots to be planted to corn were plowed on May 17, four of them deep and four shallow, as called for in the outline. The corn crop for this year follows the outline as regards depth of tillage, but was on land which was uniform with reference to crop sequence. The eight plots that should have been in wheat were fallow during the summer. They were plowed on July 13, four of them with the ordinary plow and four with the deep-tillage machine. Winter wheat was sown in the fall on four of the fallow plots and four of the plots that had been in corn. The preparation for the crop of 1913 follows the outline in its entirety as regards depth of tillage. In the particular of crop sequence the four corn plots and the four wheat plots that should have followed wheat were on fallow land. Winter wheat was used in this experiment only the one year, durum wheat having been grown since the first crop.

Ordinary plowing has been done uniformly to the depth of 7 inches with a moldboard plow of the sulky type. Deep tilling has been done to the depth of 14 inches each year. Plowing for wheat has been done in the fall; plowing for corn has been done in the spring of each year, except in preparation for the crop of 1913.

The outline was departed from in preparing for the crop of 1916. The 4 corn plots that were to be sown to wheat were not plowed, but were double-disked in preparation for seeding. The 12 other plots—4 corn plots to be planted to corn, 4 wheat-stubble plots to be planted to corn, and 4 wheat-stubble plots to be planted to wheat—were all plowed 6 inches deep in the spring of 1916.

The results of this experiment for the six years 1911 to 1916, inclusive, are given in Table XVI. The yields given in this table are arranged under 16 heads: (1) Wheat following wheat on land deep-tilled each year, plot L; (2) wheat following wheat the first year after deep tillage on land deep-tilled every other year, plot J in the odd years and M in the even; (3) wheat following wheat the second year after deep tillage on land deep-tilled every other year, plot M in the odd years and J in the even; (4) wheat following wheat on land ordinary plowed each year, plot K; (5) wheat following corn on land deep-tilled each year, plot D in the odd years and N in the even; (6) wheat following corn the first year after deep tillage on land deep-tilled every other year, plot B in the odd years and O in the even; (7) wheat following corn the second year after deep tillage on land deep-tilled every other year, plot C in the odd years and P in the even; (8) wheat following corn on land ordinary plowed each year, plot A in the odd years and Q in the even. (9–16) Eight similar combinations of crop sequence and tillage method occur with the corn crop.

At the right of Table XVI are two averages. The first needs no explanation, being the average of each method for the entire period of years. Under the corn crop the grain average is the average of the three years when grain was produced and the fodder average is the average of the total weights for the three years when little or no grain was produced. The second average is the average of the two crop sequences on similar conditions of depth of cultivation.

The results given in Table XVI show a rather striking effect of crop sequence. Wheat following corn and corn following corn are both markedly better than the same crops following wheat. This positive result is the more striking when considered in connection with the lack of difference in the average yields resulting from the very marked differences in the depth of plowing. Where wheat follows wheat the three combinations, (1) deep-tilled each year, (2) the first crop after deep tillage, and (3) the second crop after deep tillage on plots alternately deep- and shallow-tilled, exhibit no difference. The plot that received no deep tillage shows an apparent increase over any of these combinations, but a careful analysis of the results of the four plots from year to year points very strongly to the belief that this apparent increase may be within the limits of the experimental error.

TABLE XVI.—*Yields at Akron (Colo.) Field Station of wheat and corn in deep-tillage experiment for the years 1911 to 1916, inclusive*

Crop and treatment.	Previous crop.	Plot.[a]	Yield (bushels per acre).[b]									
			1911	1912	1913	1914	1915	1916	Averages.			
									Grain.	Fodder.	Similar treatment after both wheat and corn.[c]	
											Grain.	Fodder.
WHEAT.												
Deep tillage each year.	Wheat.	L	......	22.5	0.3	17.1	25.5	3.5	13.8	......	16.2	......
First crop after deep tillage.	...do....	J-M	......	22.9	.3	16.4	24.5	3.2	13.5	......	18.0	......
Second crop after deep tillage.	...do....	M-J	......	29.2	.2	14.8	22.7	2.1	13.8	......	18.7	......
Ordinary plowing...	...do....	K	......	32.8	.3	17.7	22.4	2.7	15.2	......	21.0	......
Deep tillage each year.	Corn...	D-N	......	33.0	3.5	18.7	29.6	8.1	18.6	......	......	......
First crop after deep tillage.	...do....	B-O	......	40.0	9.6	21.9	33.3	7.7	22.5	......	......	......
Second crop after deep tillage.	...do....	C-P	......	45.9	5.3	28.1	30.9	7.6	23.6	......	......	......
Ordinary plowing...	...do....	A-Q	......	54.7	10.5	31.9	30.0	6.4	26.7	......	......	......
CORN.[b]												
Deep tillage each year.	Corn...	F	1,000	45.2	2,320	20.1	35.6	1,360	33.6	1,560	29.3	1,606
First crop after deep tillage.	...do....	H-E	864	40.7	2,320	16.9	27.0	1,600	28.2	1,595	26.5	2,080
Second crop after deep tillage.	...do....	E-H	432	41.7	1,960	17.7	36.3	1,160	31.9	1,184	26.9	1,511
Ordinary plowing...	...do....	G	720	43.1	2,120	16.6	40.9	1,400	33.5	1,413	28.9	1,666
Deep tillage each year.	Wheat.	N-D	1,456	32.3	2,100	9.8	32.8	1,400	25.0	1,652	......	......
First crop after deep tillage.	...do....	P-C	3,456	37.1	2,760	10.9	26.3	1,480	24.8	2,565	......	......
Second crop after deep tillage.	...do....	O-B	1,904	21.7	2,090	11.2	32.7	1,520	21.9	1,838	......	......
Ordinary plowing...	...do....	Q-A	1,904	29.8	2,810	8.7	34.2	1,040	24.2	1,918	......	......

[a] Where two plots appear under the same heading, the crop is on the first one in the odd years and on the second in the even years.
[b] For three years, 1911, 1913, and 1916, when little or no grain was produced the yield of corn is in total pounds per acre.
[c] Example: Average yield of wheat for deep tillage after both wheat and corn is 13.8+18.6÷2=16.2.

In the four plots where wheat follows corn there is a more pronounced evidence of a positive result. The heaviest yield has been on the ordinary-plowed plot, the next heaviest from the second year after deep tillage, the third heaviest from the first year after deep tillage, and the lowest yield from the plot deep-tilled every year. This relation has been quite consistent during three of the five years for which results have been obtained. During the two other years little difference as a result of the different preparations is exhibited.

From the corn crop no significant differences as a result of different depths of tillage have been obtained. Between the average of the two plots deep-tilled each year and the average of the two plots ordinary-plowed each year there is as an average of six years' results a difference of only 0.4 bushel of corn in favor of one and 60 pounds of fodder in favor of the other. In the three years when grain was produced both of these averages exceeded those of the plots alternately deep-tilled. In the three years in which fodder only was produced, the yields of these plots exceeded those of one of the alternately deep-tilled plots, but were in turn exceeded by that of the other.

That these differences are accidental rather than due to the effect of the tillage method is shown by the fact that they are determined, in at least a part of the cases, by differences in 1911 in the yield of plots exactly similar in their preparation. The only differences of cultivation or sequence that year were that the four plots F, E, D, and C, being the four which appear under the headings "Deep tillage each year" and "First crop after deep tillage," were deep-tilled, while the other four plots were given ordinary plowing. Two of the deep-tilled plots and two of those shallow-plowed produced some grain, while the other four did not. The yields are given, however, as total weights of fodder. In no other year has there been observed in plots of different treatment such great differences as were evidenced this year between plots of similar treatment.

From the evidence presented by this experiment it is safe to say that at this station deep tillage has no efficacy either in overcoming drouth or in increasing the yields of wheat or corn in the average of a series of years. There is, indeed, strong indication that the yields of wheat may be materially reduced by this practice. The conclusiveness of this evidence is strengthened by its general agreement with the results of the shorter experiment in the use of dynamite and the longer and more extensive experiment with subsoiling.

ARDMORE FIELD STATION

DEEP TILLAGE BY THE USE OF DYNAMITE

The deep tillage with dynamite experiment at Ardmore, S. Dak., is similar to the one at the Judith Basin Field Station, and in every particular except the size of the plots and their grouping in the field is the same as the deep-tillage experiment at Akron. Figure 4 illustrates the manner in which the plots are laid out. In preparation for the crop raised in the odd years the two center tiers of plots running north and south are dynamited. In preparation for the crop raised in the even years the two center tiers of plots running east and west are dynamited. In the odd years the two north tiers of plots are cropped to wheat and the two south tiers to corn. In the even years the two east tiers of plots are cropped to wheat and the two west tiers are cropped to corn. The size of each plot is ¼ acre.

Eight plots were dynamited late in September, 1912. The charges of powder were placed 15 feet apart in each direction, ½ pound of 20 per cent powder being used in each charge. The charges were fired at a depth of 30 inches, which is as deep as is practicable to place them in this soil when it is dry. The soil on which this experiment is located is of the heaviest clay of the type commonly known as gumbo. Apparently it is almost impervious to water under some conditions, and samples taken to a depth of 10 feet reveal no change in its character. After the explosive had been used, an examination of the soil showed that it had not been in the least affected at a distance greater than 5 feet from the location of the charge. In many cases the soil was not disturbed beyond a distance of 3 feet from the charge. This was when the soil was very dry. When the soil is at all moist, the powder exerts a packing rather than a disrupting effect.

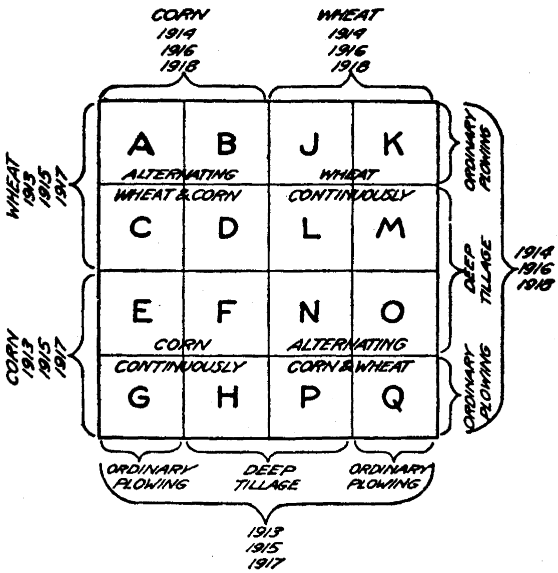

FIG. 4.—Diagram of plots in dynamiting experiment at Ardmore, S. Dak.

After the first year the powder company withdrew its active cooperation, but the experiment has been continued by the Department, and the blasting done each year as provided for in the original outline.

Each fall, after the dynamiting is completed, the entire 16 plots are plowed to a depth of 7 or 8 inches. They are left rough to overwinter, the object being to leave them in condition to catch and retain the maximum amount of snow and rainfall. In the spring the plots are given the necessary tillage with a disk and a harrow to put them in proper conditions for seeding.

In 1913 good stands of both corn and wheat were obtained. This land had produced a crop of sorghum in 1912, and consequently contained no water in storage. The season of 1913 was very dry, particularly during

June, July, and August. The wheat reached a height of only about 10 inches and probably would not have yielded as much as 1 bushel per acre. It was clipped with a mower and raked off the ground, no attempt being made to obtain yields. No appreciable difference could be observed between the plots as a result of the dynamiting. The corn crop suffered badly from drouth and did not ear. It was severely damaged by hail, and the yields were not determined. No appreciable difference could be observed between any of the plots.

In 1914 a very promising crop of wheat was destroyed on June 24 by a heavy hailstorm. The corn suffered from this storm, and again from a second one on July 7. Hail in August again damaged it to a limited extent. During the latter part of the season it suffered from lack of water and was cut for fodder on August 18. No ears were produced. Both 1915 and 1916 were productive of good crops of both wheat and corn.

Table XVII gives the yields from this experiment. They are arranged and averaged the same as the data in Table XVI, which reports the results of the deep-tillage experiment at Akron.

TABLE XVII.—*Yields at Ardmore (S. Dak.) Field Station of wheat and corn in dynamiting experiment for the years 1914 to 1916, inclusive*

Crop and treatment.	Previous crop.	Plot.[a]	Yield (bushels per acre).				
			1914[b]	1915	1916	Average.	Average of similar treatment after both wheat and corn.
WHEAT.							
Dynamite each year	Wheat	L	....	26.9	15.9	21.4	21.0
First crop after dynamite	...do	J–M	....	35.3	11.7	23.5	22.2
Second crop after dynamite	...do	M–J	....	35.7	18.7	27.2	28.3
Ordinary plowing	...do	K	....	31.5	16.1	23.8	23.0
Dynamite each year	Corn	D–N	....	25.7	15.3	20.5	.....
First crop after dynamite	...do	B–O	....	26.8	14.7	20.8	.....
Second crop after dynamite	...do	C–P	....	39.8	19.0	29.4	.....
Ordinary plowing	...do	A–Q	....	26.4	18.0	22.2	.....
CORN.							
Dynamite each year	Corn	F	632	17.4	14.7	16.1	18.7
First crop after dynamite	...do	H–E	716	40.4	15.6	28.0	26.2
Second crop after dynamite	...do	E–H	634	29.4	14.3	21.9	22.6
Ordinary plowing	...do	G	824	33.9	22.3	28.1	29.2
Dynamite each year	Wheat	N–D	860	24.1	18.2	21.2	.....
First crop after dynamite	...do	P–C	672	35.3	13.3	24.3	.....
Second crop after dynamite	...do	O–B	1,168	28.1	18.2	23.2	.....
Ordinary plowing	...do	Q–A	1,180	40.6	20.0	30.3	.....

[a] Where two plots appear under the same heading, the crop is on the first one in the odd years and on the second in the even years.
[b] Weight of fodder; no grain produced.

With the wheat crop the difference, if any, between dynamiting each year, the first year after dynamiting, and not dynamiting at all appears to be slightly in favor of the latter. The highest yields have been obtained each year both where wheat follows wheat and where wheat follows corn on plots the second year after dynamiting. The fact that these results have been obtained from four separate plots would seem to remove it from the possibility of being due to soil variation. With the corn crop the tendency has been for the land not dynamited at all to produce the highest yields. The second highest average yield has been the first year after dynamiting, the third highest the second year after dynamiting, while the lowest yields have been from those plots dynamited each year.

The results of both crops together indicate that it is very questionable whether any actual increase of yields may be obtained on this soil as a result of dynamiting. There can be no question, however, of the conclusion that there is no chance of yields being increased sufficiently to make the operation a profitable one. The experiment is being continued, however, and has been somewhat extended. In order to determine the effect of a complete loosening of the soil regardless of cost, one one-tenth acre plot was dynamited in the fall of 1915 with charges set close enough together to insure the loosening and stirring of all the soil on the plot, the charges being fired at a depth of 30 inches. In 1916 the appearance and the yield of the wheat on this plot was practically the same as that on an adjoining plot that was ordinary fall-plowed.

BELLEFOURCHE FIELD STATION

DEEP TILLAGE BY THE USE OF DYNAMITE

In October, 1912, a representative of the powder company gave a demonstration in blasting soil for field crops at the Bellefourche Field Station. A one-tenth acre plot (plot 1 in Series VIII, field B), 8 rods by 2 rods, that had been in millet (*Panicum miliaceum*) was selected for the demonstration. The shots were placed 20 feet apart each way and 3 feet deep. This plot and two adjoining plots that were used for controls had been plowed shortly before the dynamiting. The control plots (plots 1 in Series VII and Series IX) adjoined the ends of the dynamited plots, one on the east and one on the west. The soil on the plots in Series VII and VIII is uniform, but that on the plot in Series IX is poorer on account of a hardpan spot covering nearly half its area. This plot was manured.

In the spring of 1913 all three plots were treated alike and seeded to Sixty-Day oats. The dynamiting and manuring were not repeated but the plots were given uniform treatment and again seeded to oats in 1914. Both seasons spring conditions were favorable, but after the latter part of June or the first part of July the crop suffered from drouth.

In 1915 all the plots were given the same treatment and seeded to wheat, for which the season proved extraordinarily favorable. The plots were all fallowed in 1916 and seeded to alfalfa in 1917. The yields for the three years following the dynamiting are shown in Table XVIII.

TABLE XVIII.—*Yields at Bellefourche (S. Dak.) Field Station of oats and wheat in dynamiting experiment for the years 1913, 1914, and 1915*

Plot No.	Treatment.	Yield in bushels each year.		
		1913, oats.	1914, oats.	1915, wheat.
B VII-1	Fall-plowed	25.9	19.1	58.8
B VIII-1	Fall-plowed and dynamited	18.4	18.8	54.0
B IX-1	Fall-plowed and manured	24.1	16.1	52.8

The only conclusion that can be drawn from these yields is that dynamiting is not effective in increasing yields. The first year after dynamiting the effect appears to have been quite the opposite. It is impossible to say how much effect the manure used on Plot IX-1 had in overcoming the initially poor condition of that plot.

JUDITH BASIN FIELD STATION

DEEP TILLAGE BY THE USE OF DYNAMITE

An experiment similar to those at Akron and Ardmore, in the use of dynamite as a medium of deep tillage was inaugurated in the fall of 1912 at the Judith Basin Field Station. The plots are ¼ acre in size. The plan of the experiment is identical with that at Ardmore, as shown in figure 4 and described in connection with the results from that station.

The land on which this experiment was started was prairie sod broken in June, 1909, and seeded to winter wheat late in November of that year. A poor crop of wheat was harvested from the land in 1910, the yield being 10 bushels per acre. The land was plowed in the spring of 1911 and seeded to flax, which yielded 12 bushels per acre. The Judith Basin Field Station obtained possession of this tract of land in November, 1911. The field was bare -fallowed during 1912, being plowed late in June, and double-disked and harrowed three times during the remainder of the season. The plots were staked out, and the first dynamiting was done in September of that year. The entire block of 16 plots was plowed in the spring of 1913 and seeded to wheat and corn, as called for in the outline of the experiment. Very little difference could be noted in the growth of grain on the different plots during the season. At harvest time the plots were as uniform in growth and height as if they had all received the same treatment.

In preparation for the crop of 1914 dynamiting was done in the fall, but all plowing was deferred until spring. Good stands were obtained with both wheat and corn and good crops produced.

In preparation for the crop of 1915 the dynamiting was again done in the fall and the plowing in the spring. In preparing for the crop of 1916 both dynamiting and plowing were done in the fall. The plowing remained rough over the winter. In the spring all plots were double-disked and harrowed in preparation for seeding. As in previous years, no variation in growth that could be attributed to the use of dynamite could be observed in the plots in the field.

The yields from the 16 plots in this experiment for the four years 1913 to 1916, inclusive, are presented in Table XIX. The arrangement of the data in this table is the same as in Tables XVI and XVII. The yields of corn are given in total pounds of fodder per acre. The corn used in these experiments is raised for fodder at this station and no grain produced.

TABLE XIX.—*Yields at Judith Basin Field Station of wheat and corn in dynamiting experiment for the years 1913 to 1916, inclusive*

Crop and treatment.	Previous crop.	Plot.[a]	Yield.					Average of similar treatment after both wheat and corn.
			1913	1914	1915	1916	Average.	
WHEAT.								
Dynamite each year...	Wheat.	L	31.1	20.2	30.6	18.8	25.2	26.2
First crop after dynamite.	...do...	J–M	33.2	18.6	32.1	19.7	25.9	26.4
Second crop after dynamite.	...do...	M–J	30.8	17.3	29.8	19.4	24.3	25.9
Ordinary plowing.....	...do...	K	30.6	17.0	30.1	17.1	23.7	23.4
Dynamite each year...	Corn...	D–N	31.2	20.6	32.6	24.0	27.1	......
First crop after dynamite.	...do...	B–O	31.2	20.1	32.1	23.7	26.8	......
Second crop after dynamite.	...do...	C–P	27.9	23.2	32.3	26.4	27.5	......
Ordinary plowing.....	...do...	A–Q	26.7	17.3	27.9	20.6	23.1	......
CORN.[b]								
Dynamite each year...	Corn...	F	2,640	9,700	2,115	4,400	4,714	3,903
First crop after dynamite.	...do...	H–E	2,240	8,500	2,120	3,400	4,065	3,309
Second crop after dynamite.	...do...	E–H	2,880	8,700	1,695	4,600	4,469	3,998
Ordinary plowing.....	...do...	G	2,200	8,400	1,840	4,400	4,210	3,363
Dynamite each year...	Wheat.	N–D	2,580	5,700	1,685	2,400	3,091	......
First crop after dynamite.	...do...	P–C	2,480	3,400	1,530	2,800	2,553	......
Second crop after dynamite.	...do...	O–B	2,440	6,900	2,165	2,600	3,526	......
Ordinary plowing.....	...do...	Q–A	1,880	3,900	1,480	2,800	2,515	......

[a] Where two plots appear under the same heading, the crop is on the first one in the odd years and on the second in the even years.

[b] Yields of corn in pounds of fodder. No grain produced.

In the results from the wheat crop no difference is exhibited between the yields from the plots dynamited each year and from those plots dynamited every other year either where wheat follows wheat or where wheat follows corn. All of these apparently have an advantage of about 3 bushels per acre over the plots not dynamited at all.

The yields from the corn crop exhibit a marked effect as a result of crop sequence, the average yield following corn being nearly ¾ ton per acre greater than the average yield following wheat. Every plot following corn has outyielded every plot following wheat. No such marked effect or consistency of results is to be noted as a result of dynamiting. The yield of the plot dynamited each year has been practically the same as the yield the second year after dynamiting on the plot alternately dynamited and not dynamited. Both of these yields have been about 600 pounds per acre greater than those from the plot not dynamited at all and from the first year after dynamiting on the plot alternately dynamited and not dynamited. This inconsistent combination of results indicates very strongly that the variations are accidental rather than due to the effects of dynamiting.

Granting the proposition, which is by no means conclusively proved by the data at hand, that yields may be slightly increased by the use of dynamite, the possible increase is too small to hold out any hope of the operation being profitable even if the effect of the dynamite persisted for a considerable number of years.

SUMMARY OF RESULTS OF DEEP TILLAGE BY THE USE OF DYNAMITE OR SPECIAL PLOWS

In summation of the results from all stations it seems very questionable that deep tillage either by the use of special plows or dynamite has been effective in increasing yields. The most favorable evidence is with corn the second year after dynamiting at Akron; with wheat the second year after dynamiting at Ardmore; and with wheat after dynamiting at Judith Basin. The apparent increases in these cases are small and are offset by losses so that the averages of all trials with both crops show no increases over ordinary plowing.

Deep tilling by these methods, as well as by subsoiling, has been of no value in overcoming drouth.

The results offer no hope of profitably increasing the yield of either wheat or corn by means of deep tillage.[1]

RESULTS OF OTHER INVESTIGATIONS OF SUBSOILING AND DEEP TILLING

UTAH.—Experimental work has been conducted cooperatively at the Nephi, Utah, Substation since 1907 by the Office of Cereal Investigations of the Bureau of Plant Industry and the Utah Agricultural Experiment Station.

[1] These conclusions are supported and strengthened by the results of 1917, which was a year of low yields owing to drouth.

Cardon (*1*) summarizes the results of five years' work with deep tillage for winter wheat as follows:

The results of five years show that there was no advantage in deep plowing or subsoiling over shallow plowing so far as moisture conservation is concerned. There was no material difference in the yields obtained from plats plowed at different depths, varying from 5 to 18 inches. The highest average yield was obtained from plats plowed 10 inches deep, and the lowest average yield was from the plats subsoiled 18 inches deep, while the 5-inch plowing yielded higher than the 15-inch subsoiling.

ILLINOIS.—Mosier and Gustafson (*4*) report the results of investigations in Illinois as follows:

Investigations to determine the value of subsoiling in preparation for corn on gray silt loam on tight clay, the common prairie soil of the lower Illinois glaciation, have been carried on for eight years at the Odin Field, in southern Illinois. * * * With every soil treatment there was an almost uniform decrease in yield for subsoiling. The general average for eight years shows a decrease of 2.7 bushels per acre. The alleged benefit of subsoiling is the increasing of the water capacity of soils and of their ability to retain water during dry seasons. Yet in 1913 and 1914, both of which were very dry seasons, this method, as a general average, gave only the very slight increase of .5 and .7 bushels respectively. The subsoil was loosened by the plow, but ran together as soon as it was wet and became approximately as it was before. The experiments as a whole show that subsoiling on this type of soil not only does not pay, but is a losing operation, for in order to pay for the extra work involved in subsoiling, at least a three-bushel increase would be necessary.

Under the head of "Deep tilling" in the same bulletin the authors present no data of yield, but make the following statement:

Farmers are frequently urged to purchase a machine for plowing to a depth of 12 to 15 inches. There is little doubt that under certain conditions of soil and climate such plowing would be beneficial; but the results obtained by the Experiment Station in this state with the deep-tilling machine on the common prairie soil of the corn belt do not warrant recommending its purchase.

PENNSYLVANIA.—Noll (*5*) summarizes the result of three years' trial of the Spalding deep-tillage machine on the farm of the Pennsylvania State College as follows:

The soil in which this experiment was conducted is of the Hagerstown series. It varies in texture from clay loam to gravelly silt loam, but is chiefly clay loam. The surface soil is so deep that in most of the area little of the clayey subsoil was turned up. The soil is well drained.

Eight plats 35.5 ft. wide, varying in length from 902.5 ft. to 1,000 ft. were plowed at first. These were later made 957.2 ft. long and comprised .78 of an acre each.

Timothy sod was plowed for corn in the fall of 1909 and the spring of 1910, two plats being plowed with each implement in the fall and two in the spring.

In the fall of 1910 and the spring of 1911 the corn stubble land was plowed in the same way, and in the spring four plats were seeded to oats and four to beardless barley and alfalfa.

In the fall of 1911 the four plats which had received oats were plowed and seeded to wheat, two plats being plowed with each implement.

The crops for which the plowing was done were corn, oats, barley, wheat, and alfalfa, each one year.

Under the conditions named above the two kinds of plowing gave practically the same results for all the crops grown.

MISSISSIPPI.—Ricks (*6*), reporting the results of subsoiling with plow and with dynamite at the Central Mississippi Station, shows the following corn yields:

In 1913, not subsoiled, 31.8 bushels; subsoiled with plow, 25.5 bushels; subsoiled with dynamite, 27.7 bushels. In 1914 the yields were: Not subsoiled, 30 bushels; subsoiled with plow, 27.2 bushels; subsoiled with dynamite, 29.1 bushels. He says:

These plats were on a Houston clay soil of medium fertility. The subsoiling was done in March of 1913. The check plats were broken about seven inches deep. . . . . Subsoiling for corn, as well as for any other crop gives us no returns.

The same author (7) in describing the preparation of the soil for alfalfa says:

Good deep plowing where there is good drainage has given us as satisfactory results as subsoiling with dynamite or with a subsoil plow.

This is under an annual rainfall of about 60 inches.

TEXAS.—Hastings and Letteer (*2*) in reporting on the experiments in subsoiling at San Antonio, Tex., covering three years, 1910, 1911, and 1912, conclude that—

(1) Subsoiling is an expensive practice and so adds to the cost of preparation for a crop that unless materially increased yields result it can not be profitably adopted as a regular farm practice.

(2) Subsoiling has been tested at the San Antonio Experiment Farm for three years in rotation experiments with corn, cotton, and oats for hay and for grain.

(3) The yields of corn, cotton, and oats for hay and for grain have been either slightly increased or slightly decreased on subsoiled land. In no instance has the difference been significant.

(4) The depressing residual effect of subsoiling on the yields of corn and cotton was most marked when the crop was planted from 1 to 8 months after subsoiling; 15 months after subsoiling but little depressing effect was noted.

(5) In the soil-moisture studies so far made at San Antonio it has been found that subsoiling has not increased the moisture content of the soil.

(6) The results of these tests indicate that since neither the moisture content of the soil nor the yields of corn, cotton, and oats are increased by subsoiling, the practice is not advisable in connection with the crops mentioned in the San Antonio region of Texas.

RUSSIA.—Rotmistrov (*8*), in discussing the state of the drouth question, says:

Deep mellowing of the soil which all the writers on this subject unanimously regard as a matter of great importance with regard to fighting against drouth, has also very little real significance. On the Odessa field there have been more than 1,000 experiments made on the effect of deep plowing for winter and spring crops, and no difference in favor of deep [10½ inches] or even mediate [7 inches] plowing was obtained in the harvest. Investigations into the humidity of the soil also showed no difference in that respect between deep and shallow [3½ inches] plowing.

The argument in favor of deep plowing, that deeply mellowed soil imbibes more atmospheric residue [precipitation], falls through, because little residue settles on the steppes districts and it all enters the soil whether deeply plowed or not. On certain types of soil and in more northern regions deep plowing may have a beneficial effect for other reasons—airing the soil, etc.—but not as regards opposing drouth. [TRANSLATION.]

SUMMARY

Subsoiling, deep tilling, and soil dynamiting are all operations that increase the expense of production over that on ordinary plowing. They also increase the amount of labor expended on a given area, or reduce the acreage that can be prepared by a given working unit. Subsoiling is as laborious and expensive an operation as plowing, but must be done in addition to it and at the same time. Plowing with a special deep-tillage machine to a depth of 12 to 14 inches requires considerably more than double the labor, time, and expense of ordinary plowing. The use of dynamite in the least quantity that might be effective involves an added expense for material and labor of more than $20 per acre. Consequently, in order to justify their use, these practices should show increases in yields sufficient to pay for the extra expense involved.

In any year a combination of conditions favorable to subsoiling may occur at any station. At some stations the average results of a series of years shows no measurable effect on crop yields as a result of subsoiling. At other stations the effect has clearly been to decrease yields. At still other stations, particularly at Hays, Kans., subsoiling appears to have resulted in significant increases in crop yields. With some of the crops showing increases, however, the yields from either method have been too small to be profitable.

Recognizing the fact that there may be times and places giving results favorable to subsoiling or other methods of deep tilling, the average yields obtained in the extensive experiments here reported seem to warrant the conclusion that as a general practice for the Great Plains as a whole no increase of yields or amelioration of conditions can be expected from the practice.

In their relative response to deep tillage there is no marked difference to be observed between crops.

Subsoiling and deep tilling have been of no value in overcoming drouth. The effect, on the contrary, apparently has been to reduce the yields in those seasons that are below the average in production.

Experiments have been conducted with the subsoil plow, the Spalding deep-tillage machine, and dynamite. The effect or lack of effect of deep tillage appears to be essentially the same, irrespective of the means by which it is accomplished.

These conclusions are the result of extensive experiments covering a wide range of crops, soils, and conditions in the Great Plains. Experiments conducted in the Great Basin under semiarid conditions with the greater part of the precipitation occurring in the winter; under humid conditions in the States of Illinois, Pennsylvania, amd Mississippi; under semiarid conditions at San Antonio, Tex.; and under semiarid conditions on the black soil of southern Russia have all led to the same conclusion: that yields can not be increased nor the effects of drouth mitigated by tillage below the depth of ordinary plowing.

The quite general popular belief in the efficiency of deep tillage as a means of overcoming drouth or of increasing yields has little foundation of fact, but is based on misconceptions and lack of knowledge of the form and extent of the root systems of plants and of the behavior and movement of water in the soil.

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